Agro-ecology of Maize Production in Cool Mountain Land Environments: A Case Study from Upper Swat, NWFP, Pakistan

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Abbreviations

CCRI: Cereal Crops Research Institute, Pirsabak, NWFP, Pakistan.
CIMMYT: International Maize and Wheat Improvement Centre, Mexico.
MRI: Maize Research Institute, Zemun Polje, Yugoslavia.
NARC: National Agricultural Research Centre, Islamabad, Pakistan.
NZ DSIR: New Zealand Department of Scientific and Industrial Research, Biological Industries Group.
PARC: Pakistan Agricultural Research Centre, Islamabad Pakistan.
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Abstract

Cool environments in the mountain lands of Pakistan have tended to be passed over by previous green revolutions in maize and wheat. Agricultural development in these environments has lagged behind the rest of Pakistan. Major reasons for this include geographical isolation, difficult access and working conditions, and extreme variation in the agro-ecology of local maize-based farming systems.

This article (Chapter) describes a new systematic agro-ecological framework for conducting agricultural research and development in mountain land environments. Techniques and procedures were developed and field tested in working environments in NWFP and Azad Kashmir over a nine-year period between 1979 and 1987.

1.0 Introduction

Byerlee (1987) observed, that historically, agricultural development projects and improved technologies for farmers in the developing world had tended to favour resource-rich farmers and/or relatively uniform agroecological environments suitable for prescriptive approaches to farm extension (i.e. Benor and Baxter, 1984). Extreeme and oftentimes highly localized agroecological variation is, a characterisitic of mountain land agriculture in NWFP, where farmers also tend to be resource-poor (Khan et al., 1986; Byerlee et al., 1987, Heisey et al., 1988). Under these conditions, in Upper Swat (Pakistan) for example, prescriptive approaches to maize development have had little farm-level impact on resource-poor mountain land farmers.

Mountain land geomorphology accounts for sixty percent the maize production area in NWFP (Figure 1, Table 1). Similar geomorphology also predominates in maize-based farming systems in Azad Kashmir and the Northern Areas, Federally Administered Tribal Areas, and parts of the Punjab province which are above 600 masl (meters above sea level). Mountain land geomorphology accounts for at least 45 percent of the total maize growing area in Pakistan.

Data generated in the Upper Swat Valley, NWFP, Pakistan (Khan 1986; Khan et al., 1986; Byerlee et al., 1987; Khan 1987; Heisey et al., 1988; Khan, 1988;) have demonstrated that extreme localized variation in the agro-ecology of maize production is a dominant feature of maize production in cool mountain lands. Agro-ecological variation, once quantified, can however, be positively exploited for developing mountain land farming systems using interactive approaches.

Existing agro-ecological analyses (Rafique, 1976; PARC, 1980; Beg et al., 1985; PARC, 1985; Akram et al., 1988), which include maize production in Pakistan, were not designed to accomodate the degree of environmental variation typical of mountain land maize production systems. These agroecological analyses need to be expanded to address current national and provincial research and development priorities and strategies for cool season mountain lands. Increasing emphasis is being given to developing cool season maize-based farming systems in Pakistan (Govt of Pakistan, 1988).

This article (Chapter) introduces a revised approach to describing the agro-ecology of maize improvement/production in cool mountain land environments in Pakistan, using Swat as a case study. A generalized approach to agro-ecological analyses of mountain land maize production systems is presented, which can be used under a wide range of cool season environments. Particular emphasis is given to non-traditional research techniques and strategies for explaining genotype by environment interaction (GxE) in maize research and development.

2.0 Genotype By Environment Interacion in Maize

The maize plant (Zea mays L.) is a complicated organism whose growth and development (phenology) in cool mountain land environments, is affected by:

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ull hypotheses) (Steel and Torrie,
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t would be difficult to use analyses of
data from on-farm research trials and
mendations. Likewise, under these
of variance techniques could not be used
maize progenies while breeding maize
using empirical techniques (Stevens et

maize farmers in cool environments,
ymous with extreme variation/instability
and grain and fodder yields across
For example, the open-pollinated maize
CCRI (Pirsabak, NWFP), "Shaheen" which
ycle during the main season in less than
Lower Swat (Lat 34.8°N, Alt 1000

masl), takes at least 120 days to mature in Upper Swat at Kalam (Lat 35.5° N, Alt 2,000 masl).

Perspectives and techniques for agro-ecological analysis, which are described later in this article (chapter) can be used to increase the precision of analyses of variance, of data generated in mountain land environments. For example, an independent temperature-based variable, such as altitude, or growing degree days may be included in the analyses of variance model as covariates to reduce unexplained variance
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Alternatively, data sets may be partitioned into recommendation domains on the basis of geomorphology, altitude, planting date, cropping rotation etc., and analysed separately to reduce the effects of GxE on error variance[][]][][][][][[][(Paul to provide example)][[][]][] [][][][[].

Recent advances in breeding stress tolerant maize for cool environments have considerably extended the zone of adaptation of highland tropical germplasm in to higher latitude areas, including the mountain lands of NWFP, Pakistan (Eagles, 1986a,b; Eagles and Hardacre, 1988; Stevens et al., 1987a, 1988a,b). Traditionally, the agro-ecology of maize improvement programmes have been categorized on the basis of the ecologies where germplasm evolved, or was bred, for example, lowland and highland tropical, subtropical and temperate environments, respectively (CIMMYT 1985). In the light of recent advances in breeding stress tolerant maize for cool environments (reviewed by Stevens et al., 1987a), new approaches to describing the ecology of maize and GxE are needed for breeding stress tolerant maize for cool mountainland environments.

3.0 Temperature, and the Phenology of Maize

A characteristic of cool environments is that day temperatures seldom exceed 35°C for extended periods, and night temperatures usually fall below 19°C. Maize is a C4 plant, and this range of temperature is close to the optimum for plant grownth (i.e. 15-30°C). Optimum maize growth can expected, in the absence of other environmental stresses, where day temperatures do not exceed 30°C for extended periods and night temperatures approach, or fall just below the threshold of dark respiration (i.e. 10 to 15°C) (Bidwell, 1979).

Cool season environments are a feature of mountain land environments through out the developing world including temperate, continental, subtropical and tropical ecologies.

Cool season environments can also be found at lower altitudes/latitudes in temperate and continental ecologies, as well as in tropical and subtropical ecologies during winter/spring production cycles.

In the absence of other environmental stresses, seasonal development of the maize crop is positively correlated, with seasonal and daily (diurnal) variations in air and soil temperatures, especially between 15 and 25°C. This positive correlation has been exploited for many years in thermal crop development models (reviewed by, Hodges and Doraiswamy, 1979; Robertson, 1983a,b; WMO, 1981), of which examples have have been adapted to conditions in Pakistan (Stevens et al., 1987b).

Daily, and even monthly averages of maximum and minimum temperatures have been used successfully, for many years in in continental environments to predict maize phenology. In cool environments, however, the use of almost continuous, rather than daily/monthly thermal (temperature) records has been reported to improve the predictive power of maize-growth models (Stevens et al, 1986). In mountain land environments of Kalam (2,000 masl) this is especially true of maize crops planted during late April, early May, where the crop can be protected from grazing. During this period, air and soil temperatures are sub-optimal (i.e. 10 to 13°C,

Figure 2), yet day temperatures are adequate for the maize crop to germinate and grow (Figure 3).

Daily temperature data can provide a reliable first approximation (after Stevens et al., 1986) for documenting anthesis in maize crops planted into "warm soils", but not "cold soil" (i.e. 10 to 15°C). This is logical, since maximum and minimum temperature data does not record the actual duration over which thermal regimes are suitable for the maize plant to grow. This is demonstrated in Figures 3a to 3d. Particular note should be taken of the diurnal period during which air temperatures exceed 15°C, and active growth of the maize plant is possible, in the absence of other environmental stresses.

In Azad Kashmir, like Upper Swat, below 1,800 masl the maize crop is planted into warm soils, and the daily thermal model is applicable for medium and short season maize varieties planted in time for them to mature before autumn temperatures decline. Figures 4a to 4c were prepared from data collected across an altitude sequence in the mountain lands of Azad Kashmir. These data demonstrate that maize phenology is more closely correlated to air temperature than calendar days. A schedule of accumulated growing degree days (Base 10°C, Stevens et al., 1987b) is given for different planting dates at two locations at different altitudes in Swat during 1986. At least seven years data are needed to calculate long-term temperature normals, which could be used to characterize agro-climatic conditions in these environments.

The daily average maximum and minimum thermal maize growth model (Stevens et al., 1986), cannot be relied upon to document grainfill in cool environments, especially for cold tolerant germplasm. In cool environments, the rate at which morning and evening temperatures change (diurnal fluctuations), can significantly influence crop phenology. For example, with clear skies, and if temperatures quickly rise and fall above and below the threshold of dark respiration following sunrise and sunset, then the maize crop will tend to develop more rapidly than predicted using daily averages. This will be especially evident at latitudes where the period of active plant growth exceeds six to eight hours per day.

4.0 Geomorphology and Maize Phenology

In mountain land environments, where other environmental stresses are minimal, light intensity/photoperiod, and temperatures may vary considerably with changes in landform. This causes local microclimates, which may, for example, be reflected in increased variation in crop development. A corresponding increase of variation in experimental results may follow.

Slopes facing the sun tend to be warmer than those which do not. Cold air, which is heavier than warm air, tends to settle on the floors of valleys, which may causing an inversion layer of warm air at higher altitudes along the sides of valleys. Depending on landform, diurnal and/or seasonal fluctuations in air temperature may also cause abnormal drainage patterns of cold/warm air, for example cold air draining south from higher latitudes during the winter.

At a constant latitude, mean daily temperatures decrease with increasing altitude at the rate of approximately 5°C per 1,000 m (i.e. the lapse rate). Likewise, mean temperatures decline with increasing latitude, at a constant altitude. Variations in altitude and latitude influence the phenology of maize due to the associated change in thermal regimes. This is independent of any photoperiod response associated with changing daylength. The influence of altitude, latitude, and air/soil temperature on crop phenology is, therefore, confounded.

Depending on its origin, maize germplasm reacts differently to changing day length. For example, lowland tropical maize is more sensitive to changing photoperiod than temperate maize (Lee and Brewbaker, 1977; Kinery et al., 1983). Abnormal photoperiod effects in maize have been recorded in the bottoms of narrow valleys in Kaghan and Gilgit, especially those running in a north south direction, and lying at higher altitudes/latitudes.

Many plant species have definate temperature requirments for their optimum growth and survival. In mountain land environments, temperature variation is correlated with landform, as are other major ecological variables, including soil forming factors, which influence the natural production potential of soils. The composition of local indigenous flora is often positively correlated with variations in geomorphology, i.e. increasing altitude, and changing aspect, as shown for Swat in Figure 5 (Soil Survey of Pakistan, 1976).

The vegetation/crop ecology, or bioclimate approach described by Beg et al. (1985), and Baig and Ali (1986, Figure 6) to agro-ecological analyses can be extended in mountain lands to include the distribution and phenology of a wide range of temperature sensitive horticultural and arable crop plants, including maize, wheat, tomatoes, and brassica.

5.0 Agro-ecology of Maize-based Farming Systems in NWFP

The agro-ecology of maize production in NWFP is dominated by the proximity of the Himalayan mountain land systems in the north and west of the Province. Mountain lands dominate basic agricultural resources of geology, geomorphology, climate and seasons, soils, and vegetation ecological zones in NWFP.

5.1 Soil Surveys

The ecology (Ahmad, 1986) and texture (Soil Survey of Pakistan, 1971) have been summarized, and mapped (Figures 7 and 8). Additional introductory information is contained in the Atlas of Pakistan (Survey of Pakistan, 1986).

A comprehensive reconnaissance series of soil surveys (Soil Survey of Pakistan) have been completed at a scale of 1:63,000 and supported by aerial photographs for all agroecological environments in NWFP which support major maize-based farming systems. Although much of the cropping, landuse, and to a lesser extent land capability data in these publications are now out of date, they continue to provide an invaluable historic base-line. Soils (at series level) and landform, which have been mapped at a scale of 1:250,000 by the Soil Survey of Pakistan are especially useful documents for developing a sequential approach to mapping recommendation domains for agricultural research and develoment activities.

Natural vegetation, which is described in these reconnaissance surveys on the basis of increasing altitude. These descriptions provide effective field indicators of boundaries to various recommendation domains for maize production. For example, the transition zone between chir pine and pure kail in Swat (Figure 5) coincides with the altitude range above which it becomes difficult to grow the mid-season maize variety Azam (CCRI, Pirsabak) in a maize-wheat rotation. It is in this zone where farmers start to become increasingly interested in short-season varieties such as Shaheen (CCRI, Pirsabak), if they plant maize after wheat, which has been harvested for grain, rather than fodder.

5.2 Maize Production Zones

The agro-ecology of maize production in the mountain lands of Swat is representative of more than fifty percent of the total maize growing area in NWFP (Table 1). Kharif (summer) agro-ecological zones for producing maize are delineated on the basis of altitude, irrigation status, and geomorphology. Maize is not grown as a winter/spring crop in the mountain lands of NWFP, however, winter maize was grown successfully on an experimental basis at CCRI (Alt 480 masl Lat 34.0°C) during 1987-88. Spring maize production is a regular feature of CCRI's maize breeding and foundation seed programme. Winter maize breeding and seed increase programmes have been conducted by CCRI in DI Khan (Alt 400 masl, 31.8°C) on a number of occassions over the past five years. Here, reliable and economic yields of maize seed was harvested from early- and mid-season maize varieties in time to plant in cool environments below 2,000 masl, north of Lat 34°C.

In the mountain lands of NWFP, maize is grown as a multipurpose crop for grain and fodder, usually as a subsistance crop, and seldom only for the cash value of grain. Livestock are an important component of farming systems, and many farming families depend on supplimentary off-farm income, and/or speciality fruit and vegetable cash crops. At higher altitudes, adjacent to forest areas, firewood is sold as a source of cash. Increasingly, mountain land farmers are moving away from traditional mono-cropping practices of growing full-season maize varieties, in favour of planting earlier maturing wheat and maize varieties which facilitate the adoption of more intensive cropping patterns.

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5.3 Ecology of Maize, Rainfall, and Geomorphology

Essentially, all agro-ecological environments which support major maize-based farming systems in NWFP are either mountain land, or closely linked with adjacent mountain land systems; in that they have a dominant effect on the six basic agricultural resources mentioned above. Variations in rainfall, temperature, and soil type appear to be the major variables affecting the ecology of maize, which are closely correlated with variations in landform, especially altitude and aspect.

Long-term rainfall distribution patterns (Figure 9) within all major maize growing environments of NWFP are influenced by mountain lands. For example, mountain lands within, and adjacent to NWFP provide catchment areas for precipitation resulting from western disturbances during the winter, deflects monsoon rains, and generate local rainfall patterns, from thermal activity (Pakistan Meteorological Department, 1986).

Mountain lands, have direct impact on total rainfall and its seasonal distribution within non-irrigated maize production environments on "subrecent level terraces and flood plains" as well as the "dissected plains" (Figure 1) in the Peshawar Valley. Likewise, maize production on "bahadas" in southern districts of NWFP largely depend on the agro-ecological impact of adjacent mountain lands. These production systems cannot, however, be considered maize-based.

The availability and supply characteristics of major and minor irrigation systems throughout NWFP are closely linked with the mountain land ecology of their catchment areas. Winter precipitation originating from on average 20 western disturbances during December to March (Pakistan Meteorological Service, 1986) provide the major source of irrigation water for maize production in NWFP.

Moonsoon rainfall is erratic in NWFP, declining in a westerly and northerly direction. Monthly and monsoon normal (1931-60) isohyetal maps have been published by the Pakistan Meteorological Department (1971, Figure 9). The province lies on the western and northern margins of the monsoon system, which originates in the Bay of Bengal, and moves north and west, as the season progresses (Pakistan Meteorological Service, 1986).

6.0 Conclusions

Increasingly, starting in the the mid 1980's, constraints to the developing maize-based farming systems in the mountain lands of NWFP have been reduced. The report of the National Commission on Agriculture represented a milestone in the history of mountain land development in NWFP. Following the publication of this report, increased international and national focus has been attracted to the needs of farming families in cool mountain land environments in Pakistan (and

Afghanistan). This includes an increasing awareness of the down-stream benefits of research and development resources directed toward mountain land environments.

On-farm research, and back-up research support, including agro-ecological analyses, associated with the Swat On-farm Programme have contributed significantly to the development of agricultural technologies, which are acceptable to mountain land farmers in NWFP.

Table 1. Major agroecological maize production environments of NWFP, kharif season (excluding Fata). Area in hectares.

Zone/District	Area by Irrigation Status: Irrigated	Rainfed	Total	Geomorphology**
Warm-season Environments				
Low-altitude (<900 masl)				
Abbottabad	3,100	30,000	33,100	MNT
Bannu	15,500	920	16,420	BHDS/DST
D.I. Khan	2,200		2,200	BHDS
Kohat	4,200	7,700	11,900	MNT
Malakand	5,200		5,200	SRFP/MNT
Manshera	3,100		3,100	MNT
Mardan	56,156	4,846	71,002	DP/SRFP/MNT
Peshawar	40,877	319	41,196	DP/LVP/SRFP/DST/BHDS
Swat		10,000	10,000	SRFP/MNT
Totals	140,333	53,785	194,118	
Cool-season Environments*				
Mid-altitude (900 to 1,800 masl)				
Abbottabad	3,200	21,000	24,200	MNT
Chitral	3,500		3,500	MNT
Dir	9,400		9,400	MNT
Kohistan	23,000		23,000	MNT
Mansehra	3,000	45,000	48,000	MNT
Swat	20,000	43,000	63,000	MNT
Totals	62,100	109,000	[illegible]	
High altitude (>1,800 masl, mixed irrigated/rainfed)				
Abbottabad	4,000		4,000	MNT
Chitral	3,500		3,500	MNT
Dir	5,500		[illegible]	MNT
Kohistan	3,600		3,600	MNT
Mansehra	21,000		21,000	[illegible]
Swat	19,200		19,200	MNT
Totals	57,200		[illegible]	
Grand Total (excluding Fata)			422,410	

* Cool-season environments [illegible] for extended periods [illegible] night temperatures usually drop below [illegible].

** Geomorphology Abbreviations:

Pleistocene River Terraces
- Dissected Silty Terraces: DST

Subrecent Level Terraces
- Kabul and Swat Terraces: KST

Flood Plains
- Subrecent Flood Plains: SRFP

Loess Plains
- Level Plains: LVP
- Dissected Plains: DP

Piedmont Plains
- Bahadas: BHDS

Mountains
- Mountains: MNT

Table 2. Growing-degree-days (base 10°C) for two locations in Swat, 1986.

Period	Calendar Days	Growing-degree-days	
		Kabal+	Garshin++
June 1 to Sept 30	123	2320	1821
June 1 to Oct 10	133	2200	1981
June 1 to Oct 20	143	2310	2081
June 1 to Oct 30	153	2410	2200
June 10 to Sept 30	113	1875	1700
June 10 to Oct 10	123	2050	1861
June 20 to Sept 30	103	1940	1583
June 20 to Oct 20	113	1960	1860
June 20 to Oct 31	133	2060	1950
June 25 to Oct 10	108	1976	1740
June 30 to Oct 20	113	2010	1740
July 7 to Oct 10	96	1940	1496
July 7 to Oct 20	106	2040	1596
July 15 to Oct 20	98	2150	1691

+Alt 875 Lat 34.6 ++Alt 1,180 Lat 35.0

List of Figures